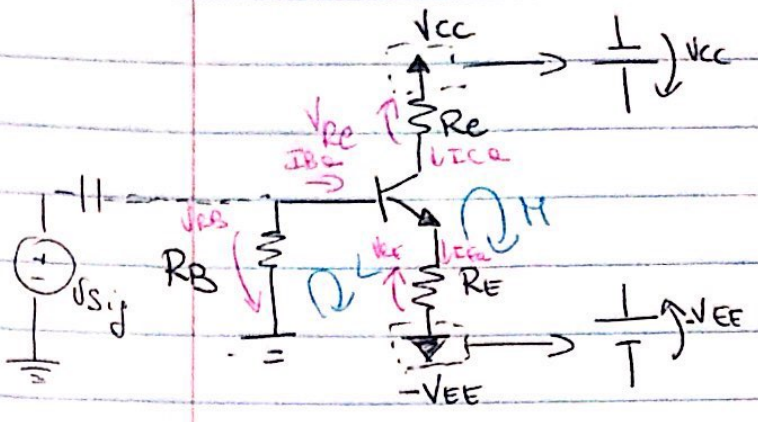
In class problem 1



Notation:

$V_{AB} \Rightarrow DC$

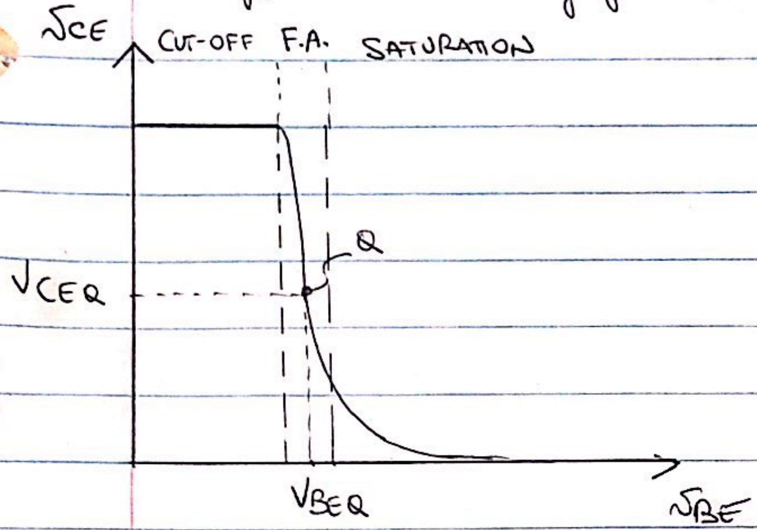
$v_{AB} \Rightarrow DC + AC$

$v_{ab} \Rightarrow AC$

Assuming small-signals is what we are dealing with

$v_{AB} = V_{AB} + v_{ab}$

Let's initially work on satisfying the requirement about the open-circuit voltage gain and the maximum swing.



$$A_v = \left.\frac{d v_{CE}}{d v_{BE}}\right|_{v_{BE} = V_{BEQ}} \quad (1)$$

1) Doing a KVL @ the loop H and considering the DC+AC signals, we obtain

$$-V_{EE} + R_E i_E + v_{CE} + R_c i_c - V_{cc} = 0 \quad (2)$$

$$v_{CE} = V_{cc} + V_{EE} - (R_E + R_c) i_c \; (3) \quad (i_E \simeq i_c)$$

$$i_C = I_S e^{v_{BE}/V_t} \quad (4)$$

$$v_{BE} = V_{BEQ} + v_{be} \quad (5)$$

$$v_{CE} = V_{CC}+V_{EE} - (R_E+R_C)\cdot I_S e^{V_{BEQ}/V_t}\cdot e^{v_{be}/V_t} \quad (6)$$

$$A_v = \frac{dv_{CE}}{dv_{BE}}\bigg|_{v_{BE}=V_{BEQ}} = -\frac{R_C+R_E}{V_t} I_S e^{V_{BEQ}/V_t} e^{v_{be}/V_t}\bigg|_{v_{BE}=V_{BEQ}} \quad (7)$$

$$A_v = -\frac{R_C+R_E}{V_t} I_S e^{(V_{BEQ}+v_{be})/V_t}\bigg|_{v_{BE}=V_{BEQ}} = -\frac{R_C+R_E}{V_t}\cdot I_S e^{v_{BE}/V_t}\bigg|_{v_{BE}=V_{BEQ}} \quad (8)$$

$$A_v = -\frac{R_C+R_E}{V_t}\underbrace{I_S e^{V_{BEQ}/V_t}}_{I_{CQ}} = -\frac{R_C+R_E}{V_t}\cdot I_{CQ} \quad (9)$$

$$|A_v| = \frac{R_C+R_E}{V_t}\cdot I_{CQ} \quad (10)$$

As V_t and I_{CQ} are fixed, in order to maximize the gain, we need to maximize (R_C+R_E).
At this point let's consider the requirement about the swing: $-2 \le v_O \le 2$ (11) ($^* v_O = V_O + v_o$)
The (11) translates into the condition below:
the BJT is to remain in forward active mode for $V_O \pm 2$.
The BJT will remain in forward active mode as long as $v_{CE} > V_{CE,SAT}$ and v_{CE} $V_{CE,\,cut\text{-}off}$
$0.3 \le v_{CE} \le 15$ (12) ($^* V_{CE,SAT}=0.3V$; $V_{CE\,cut\text{-}off} = V_{CC}+V_{EE}$)
Now if we consider that $v_{CE} = v_C - v_E = v_O - v_E$

$$0.3 \le v_O - v_E \le 15 \quad (15)$$

Remember that

$$v_O = \underset{(DC)}{V_O} + \underset{(ac)}{v_o} \quad \text{and} \quad v_E = \underset{(DC)}{V_E} + \underset{(ac)}{v_e}$$

Thus, we can write

$$0.3 \leq V_O + v_o - (V_E + v_e) \leq 15$$

We can then utilize the condition on the maximum swing for the output voltage

$$V_O - 2 - (V_E + v_e) \geq 0.3\,V$$

$$V_O + 2 - (V_E + v_e) \leq 15\,V$$

$$V_O = V_C = V_{CC} - R_C I_C$$

$$V_E = -V_{EE} + R_E I_E$$

$$V_{CC} - R_C I_C - 2 + V_{EE} - R_E I_E - v_e \geq 0.3\,V$$

$$V_{CC} - R_C I_C + 2 + V_{EE} - R_E I_E - v_e \leq 15\,V$$

$$10 - (R_C + R_E) I_C + 5 - 2 - v_e \geq 0.3\,V$$

$$10 - (R_C + R_E) I_C + 5 + 2 - v_e \leq 15\,V$$

$$13 - (R_C + R_E) I_C - v_e \geq 0.3\,V$$

$$17 - (R_C + R_E) I_C - v_e \leq 15\,V$$

$$-(R_C + R_E) I_C \geq 0.3V - 13V + v_e$$

$$-(R_C + R_E) I_C \leq 15 - 17 + v_e$$

$$(R_C + R_E) I_C \leq -0.3 + 13 - v_e$$

$$(R_C + R_E) I_C \geq -15 + 17 - v_e$$

$$(R_C + R_E) \leq \frac{12.7 - v_e}{I_C}$$

$$(R_C + R_E) \geq \frac{2 - v_e}{I_C}$$

The value of v_e can be neglected w.r.t. 12.7, given that $v_{e,pp} = 0.04V$

Thus $R_C + R_E$ is limited by the condition below

$$(R_C + R_E) \leq \frac{12.7}{I_C} \qquad I_C = 1mA$$

$$R_C + R_E \leq 12.7\ K\Omega$$

As we wish to maximize the gain, we will select $R_C + R_E = 12.7\ K\Omega$.

We can now determine R_E from a KVL @ the input loop and applying the condition of bias-stable design.

$$I_E = \frac{V_{EE} - V_{BE(on)}}{R_E + \frac{R_B}{\beta+1}} \simeq \frac{V_{EE}}{R_E} = \frac{5}{R_E}$$

$$I_E \simeq I_C = 1mA$$

Thus

$$R_E = 5k\Omega$$

$$R_C = 12.7\,k\Omega - 5K\Omega = 7.7\,k\Omega$$

When it comes to the resistor on the base, we can select it based on the need for forward active operation of the transistor.

$$V_{BE} = V_{BE(on)} = 0.7\,V$$

$$V_B - V_E = 0.7V$$

$$V_B = R_B I_B = R_B \frac{I_C}{\beta}$$

$$R_B \frac{I_C}{\beta} - (-V_{EE} + R_E I_E) = 0.7\,V$$

$$R_B \frac{I_C}{\beta} + 5 - 5k \cdot I_C = 0.7V$$

$$R_B \frac{I_C}{\beta} = 0.7V$$

$$R_B = \frac{0.7 \cdot 200}{1m} = 140K\Omega \Rightarrow$$

This value of R_B is small enough to satisfy the condition of a bias-stable design or $R_B \ll (\beta+1) R_E$

$$(\beta+1) R_E = 201 \cdot 5k \simeq 1\,M\Omega$$

Finally let's calculate the V_{CE} to verify that the BJT is in forward-active region

$$V_{CE} = V_C - V_E$$

$$V_E = 0$$

$$V_C = V_{CC} - R_C I_C = 10 - 7.7K \cdot 1m = 2.3\,V$$

$$V_{CE} > V_{CE,SAT}$$

The Q point is close to the saturation region, within the forward active mode operating region as the center of the active region corresponds to a $V_{CE} \simeq \frac{V_{CC} + V_{EE}}{2} = 7.5\,V$